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Experimental Study of V-Through Solar Water Heater for Tilt Angle and Glass Transmissivity

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Abstract

Solar water heaters are widely used for heating water for both domestic as well as industrial purpose. In this paper, thermal efficiency performance of V-Through SWH installed at Jaipur, India for varying tilt angle and presence of dust particles on glass cover are examined. It has been found that increasing the tilt angle from 15° to 25°, average thermal efficiency of SWH increased from 27% to 30 % and dust deposition reduced the thermal efficiency of SWH from 30% to 20% for fully clear glass to fully dusty glass for a constant tilt angle of 25°.

Keywords: Flat plate collector; thermal performance; thermal efficiency; tilt angle; V-trough collector

1. Introduction

Today's era energy conservation is one most important concern and lot of energy is required for heating water for both domestic as well as industrial purpose. Solar water heaters are the solution to the above problem due to the use of abundant freely available solar energy for most of the globe.SWH converts the solar radiation into thermal energy which heat the water or any other heat transfer fluids.

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Nomenclature

SWH	Solar Water Heater
T_1	Temperature at Copper tube surface
T_2	Temperature at middle
T_3	Temperature at water storage tank
T_4	Temperature at outlet
T_5	Atmosphere temperature

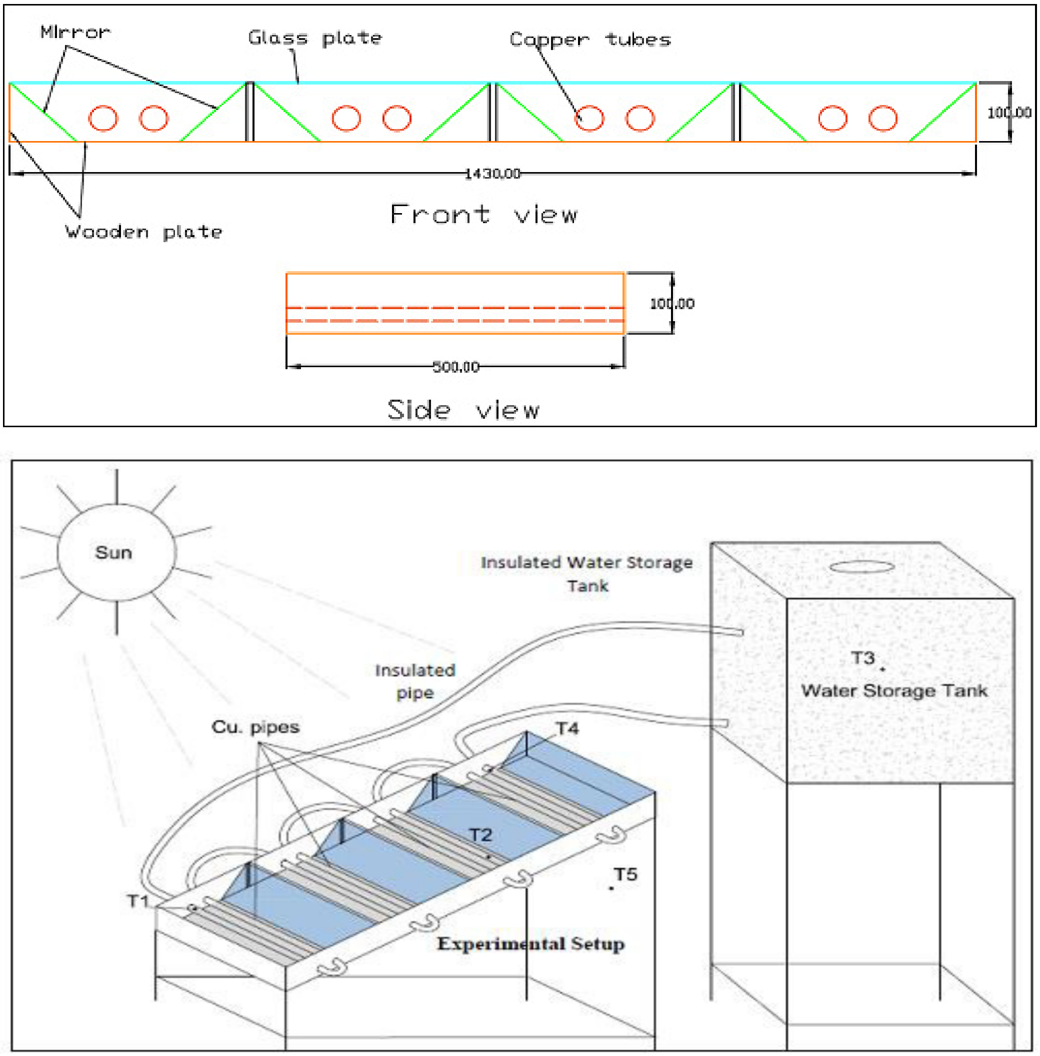
SWH can be classified by many way, on the basis of water circulation (1) Passive SWH (Thermosyphon system) and (2) Active SWH. Passive SWH works on the principle of 'Thermosyphon Process' which states that, cold water in the SWH absorber tubes gets heated due to solar radiation and rises to the top and again cold water takes the place of hot water and cycle continue until the temperature of water equalized in the water tank and absorber tubes. Active SWH uses external source like pump for water circulation in the system. On the basis of construction SWH can be classified as (1) Flat plate collector and (2) concentrating collectors.

In this study, flat plate passive swh was used with mirrors to concentrate solar radiation on the absorber tubes and it is known as v-through solar water heater and the performance of the v-through SWH has been examined for varying its tilt angle from ground and dust deposition on the glass plate.

Many researchers has performed various study for better performance of solar collector, some work are listed here. Chong et al. [1] developed a forced circulation solar water heater system which was cost effective cum easy fabrication. The experimental result shows that V-trough reflectors have improve the efficiency of the solar water heater. The advantage of easy fabrication, cost effective and high thermal efficiency of the novel stationary V-trough solar water heater with the maximum solar concentration ratio of 1.8 suns and its optical efficiency was 70.54% or 1.41 suns at the temperature of 85.9°C was obtained. Jaisankar et al. [2] studied that efficiency of solar thermal conversion and solar electric direct conversion system were 70% and 17% respectively, hence solar water heater are of great importance for domestic water heating. Prud'homme and Gillet [3] designed one major structural improvement which consists of three smaller but different length supplementary heater instead of single heater to achieve the high performance advance control policy using pumps which drive the fluid in the collector loop and the three electrical elements was proposed and validated. Abu-Mulaweh [4] developed a solar water heating system that the solar collector rotated as the sun position/angle was changed and the control system was designed to achieve this task. Results show that the water from the tank was heated by the solar energy being absorbed by the solar collector by which the thermo-syphon effect was attained which eliminated the need of circulating pump. Helal et al. [5] examined an integrated collector/storage solar water heater made in the National School of Engineers of Gabels and this water heater was equipped with a concentration system. For better absorption of solar radiance, it used reflector of three parabolic branches and compared with asymmetrical CPC and symmetrical CPC, which results the energetic performances despite the simplicity and the little cost of the collector. Liu et al. [6] studied experimentally on performance of Thermo-syphon Solar Water Heaters in Series. In this experiment, eight typical Taiwanese solar water heaters were connected in series and degree of temperature stratification and thermo-syphon flow rate in a horizontal tank were obtained. Li et al. [7] investigated numerically the flow and heat transfer performance of solar water heater with elliptical collector tube which was in tune with the experimental data and found that the Nusselt number decreases with elliptical collector tube as compared to circular collector tube from the temperature range of 273-313K. Deng et al. [8] designed a novel flat plate SWH using micro heat pipe array sprayed solar selective coating and arranged closely as the absorber of collector, which shows better thermal efficiencies than normal SWH. Similar study was done by Zhu et al. [9] on a novel solar air heater with flat micro-heat pipe arrays (FMHPA) which have better thermal efficiencies than normal solar air heater. Yao et al. [10] performed numerical simulation on solar water heaters for different initial temperatures (ranging from 273-313K) with twist tape inserts, which results the heat transfer at relatively high temperature were favored by twist tape and not useful for heat transfer at relatively low temperature.

2. Experimental Set Up and data collection

Fig. 1 (a) shows the elevation and side view of present model and Fig. 1 (b) shows the schematic diagram of Experimental set-up.



a

b

Fig. 1. (a) Elevation and side view of experimental set-up (b) Schematic diagram of experimental set-up

Effective basin area of V-through flat plate collector water storage system was 1.0 m^2. The heights, breath and length of the SWH were 100 mm, 650 mm and 1500 mm respectively. SWH was made by wooden ply and cover of clear glass of 5 mm thickness. All sides of a SWH were insulated by 40 mm thick thermo cool sheets from an environment to reduce heat losses. The inner base surface of the SWH painted with white paint to increase the reflectivity to solar radiation and black paint used on outer surface of copper pipes to increase the absorption of solar radiation and productivity of a SWH. The pipe's material was copper because it has maximum thermal conductivity. The set up consist of 4 sections, in which, the total eight pipes were used for all sections. Each section consisted of 2 tubes and tubes were attached together and these were 0.8m long and 1.5-inch diameter. Table 1 represents the materials and instruments used for this work and their purpose.

Table 1 Materials & Instruments used for this work and their purpose

S. No.	Material/Instrument	Purpose
1	Copper pipe	Fluid flowing and high thermal conductivity material
2	Wooden Wall	Insulating Walls
3	Glass	Transparent Layers
4	Pipes	Inlet/Outlet
5	Black paint	Absorber Paint
6	White paint	Reflectivity Paint
7	Solarimeter	Measuring Solar Radiation
8	Data Logger	Temperature Measurement
9	Thermocouple Wire	Temperature measuring device
10	Water Tank	Water storage tank
11	Mirror	Reflect the solar radiation
12	Glass wool	Insulating Material

The experiments were conducted in clear sky conditions with clear glass of SWH having tilt angle of 15°, 20° and 25° and data were collected, which has shown in the Table 2, 3 and 4 respectively. The experiments also have been conducted for partially dusty and fully dusty glass plates having tilt angle of 25°, which has shown in the Table 5 & 6 respectively.

Table 2 Recorded Data with clear glass and tilt angle = 15°

Time (Hr)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	Direct Radiation (W/m2)	Diffuse Radiation (W/m2)	Global Radiation (W/m2)	Thermal Efficiency
9	33	26	30	27	28	263	187	450	21
10	42	36	35	34	32	468	194	662	31
11	48	44	41	37	34	528	208	736	26
12	59	57	49	46	33	709	209	918	32
13	69	65	55	53	33	716	204	920	43
14	68	63	56	53	32	692	185	877	39
15	60	57	53	46	31	679	168	847	21
16	56	54	51	43	29	653	117	770	17
17	47	43	45	38	28	557	98	655	11

Table 3 Recorded Data with clear glass and tilt angle = 20°

Time (Hr)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	Direct Radiation (W/m2)	Diffuse Radiation (W/m2)	Global Radiation (W/m2)	Thermal Efficiency
9	34	30	31	27	24	473	144	617	14
10	40	37	32	32	28	616	180	796	28
11	51	43	40	36	30	688	198	886	36
12	60	56	45	45	31	723	208	931	46
13	61	62	49	49	32	726	210	936	37
14	66	63	53	51	31	701	204	905	42
15	61	56	51	44	32	622	196	818	34
16	55	52	48	42	31	505	163	668	30
17	42	42	42	37	29	308	108	416	4

Table 4 Recorded Data with clear glass and tilt angle = 25°

Time (Hr)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	Direct Radiation (W/m2)	Diffuse Radiation (W/m2)	Global Radiation (W/m2)	Thermal Efficiency
9	35	24	30	31	25	465	150	615	24
10	45	45	36	40	29	595	193	788	33
11	50	40	44	33	30	683	208	891	20
12	55	36	40	33	30	723	217	940	48
13	60	64	51	50	30	729	218	947	26
14	63	59	53	48	30	701	212	913	32
15	62	63	53	49	29	638	196	834	31
16	58	50	51	40	27	517	168	685	31
17	43	37	40	34	25	306	115	421	20

Table 5 Recorded Data with partially dusty glass and tilt angle =25°

Time (Hr)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	Direct Radiation (W/m2)	Diffuse Radiation (W/m2)	Global Radiation (W/m2)	Thermal Efficiency
9	33	30	27	24	23	387	86	473	38
10	39	33	35	31	26	462	150	612	23
11	47	39	41	34	29	593	192	785	21
12	54	45	45	42	30	682	207	889	30
13	61	59	52	51	31	721	217	938	26
14	59	52	51	50	30	727	219	946	24
15	58	39	50	44	30	700	211	911	26
16	54	36	47	39	29	636	196	832	26
17	47	34	42	36	27	515	167	682	21

Table 6 Recorded Data with fully dusty glass and tilt angle = 25°

Time (Hr)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	Direct Radiation (W/m2)	Diffuse Radiation (W/m2)	Global Radiation (W/m2)	Thermal Efficiency
9	27	22	25	22	26	172	180	352	22
10	34	29	30	27	29	522	229	751	13
11	41	36	38	36	30	564	284	848	12
12	50	49	44	40	31	105	292	397	49
13	54	52	48	50	31	461	345	806	22
14	50	48	46	46	30	518	277	795	15
15	46	44	44	44	29	527	236	763	10
16	44	41	41	42	27	282	212	494	14
17	38	37	36	33	25	135	117	252	23

3. Uncertainty Analysis

The uncertainty calculations for different parameter are presented here by using standard deviation formula. Formula of Reynolds number can be written as:

$$R_e = \frac{4\dot{m}}{\pi D \mu}$$

Where m is mass flow rate and D is diameter of tube and μ is viscosity of fluid. Error presented in Re number can be calculated as:

$$\frac{U_{re}}{Re} = \sqrt{\left(\frac{U_m}{m}\right)^2 + \left(\frac{U_\mu}{\mu}\right)^2}$$

Here U is % uncertainty of selected parameter. Error found out in mass flow rate value is equal to 0.01% and error in viscosity is equal to 0.12%. After calculation error present in Re number is equal to 0.12%. Similarly total error present in heat flux, heat transfer coefficient and Nusselt number is found out to be 0.225%, 1.22% & 1.22% respectively.

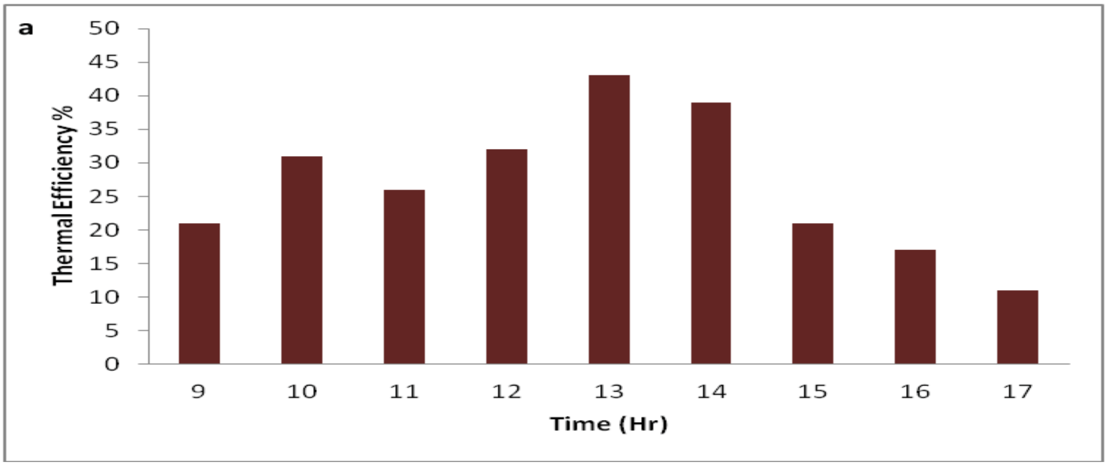
4. Result and discussions

4.1. Effect of tilt angle on thermal efficiency

The maximum thermal efficiency has been achieved when sun was perpendicular to the absorber plate of solar water heater and it has been observed that when the tilt angle increases from 15° to 25° the thermal efficiency increases.

4.2. Effect of dust particles on thermal efficiency

The dust particles reflect the solar radiation into environment so less solar radiations were available for absorption at the absorber copper tubes and hence average thermal efficiency decreases. Fig. 2. (a) , 2 (b) & 2 (c) show the variation of thermal efficiency of SWH with clear glass and tilt angle of 15°, 20° & 25° respectively. Fig. 3. (a) & 3 (b) show the variation of thermal efficiency of SWH with partially dusty and fully dusty glass with tilt angle of 25° respectively.



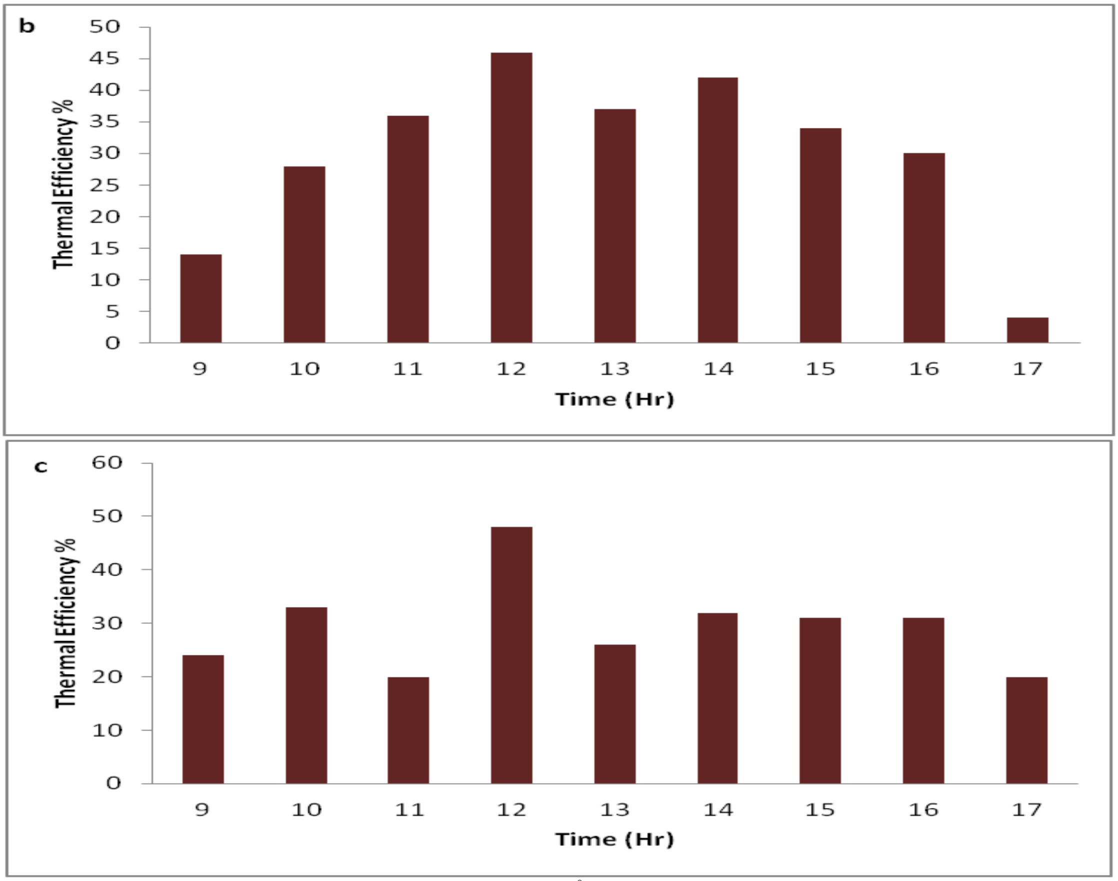


Fig. 2. (a) Thermal efficiency of SWH with clear glass and tilt angle of 15° (b) Thermal efficiency of SWH with clear glass and tilt angle of 20° (c) Thermal efficiency of SWH with clear glass and tilt angle of 25°

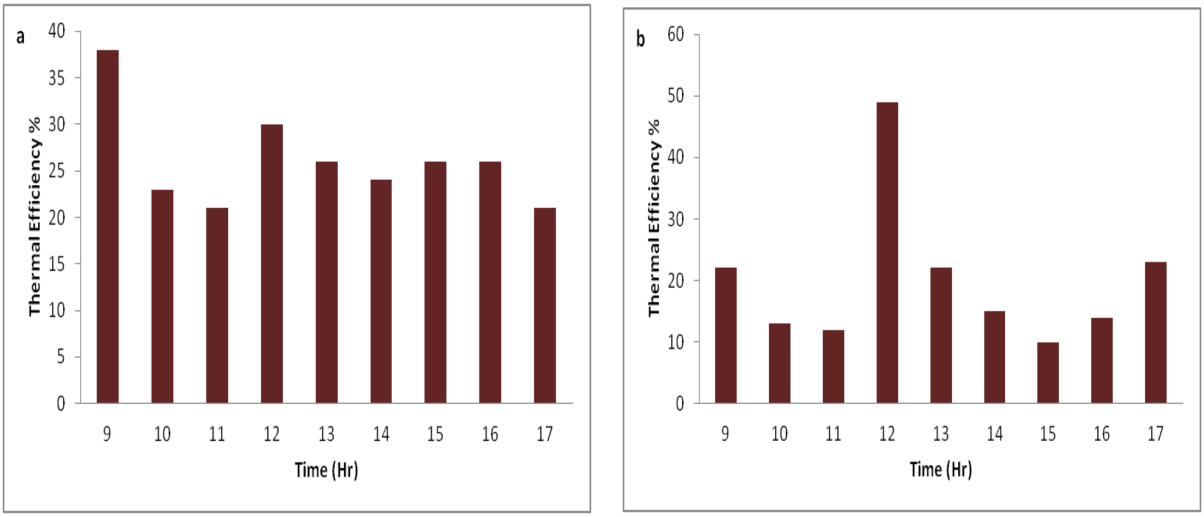


Fig. 3. (a) Thermal efficiency of SWH with clear glass and tilt angle of 25° (b) Thermal efficiency of SWH with partially dusty glass and tilt angle of 25°

5. Conclusions

The following conclusions have been made from the above discussions:

- For Jaipur increasing the tilt angle from 15° to 25°, the average thermal efficiency of SWH increases from 27 % to 30 %
- Also there was increase in maximum and minimum thermal efficiency of SWH for increasing the tilt angle from 15° to 25°
- Dust deposition reduced the thermal efficiency of SWH form 30% to 20% for fully clear glass to fully dusty glass in clear sky conditions respectively.
- Constant dust removal from the glass plate can result in better performance of the SWH.

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